



# DOE Office of Electricity TRAC

Peer Review

U.S. DEPARTMENT OF  
**ENERGY** | OFFICE OF  
**ELECTRICITY**

## PROJECT SUMMARY

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# **Design, Deployment, and Characterization of the World's First Flexible Large Power**

The project objective is to design, build, and deploy the world's first flexible large power transformer (LPT). The prototype is a 165kV, 60/80/100MVA autotransformer with three LV ratings including 57.5kV, 69kV and 80.5kV and a leakage impedance adjustable online from 4.3% to 9.3%. A flexible transformer protection system is also developed. Anticipated results include an >99.5% efficiency; a size and weight within 120% of comparable conventional LPT; compliance with IEEE standards C57.12.00 and C57.12.90; 6 months of field-testing data demonstrating comparable performance with conventional LPT.

## PRINCIPAL INVESTIGATORS

Dr. Ibrahima Ndiaye, Technology Manager, GE Research

Mr. Enrique Betancourt, Applied R&D Manager, Prolec GE

## WEBSITE

<https://www.ge.com/research/#>

# The Numbers

DOE PROGRAM OFFICE:

**OE – Transformer Resilience and  
Advanced Components (TRAC)**

FUNDING OPPORTUNITY:

**DE-FOA-0001876**

LOCATION:

**Niskayuna, New York**

PROJECT TERM:

**10/01/2019 to 05/31/2022**

PROJECT STATUS:

**Incomplete**

AWARD AMOUNT (DOE CONTRIBUTION):

**\$2,375,922**

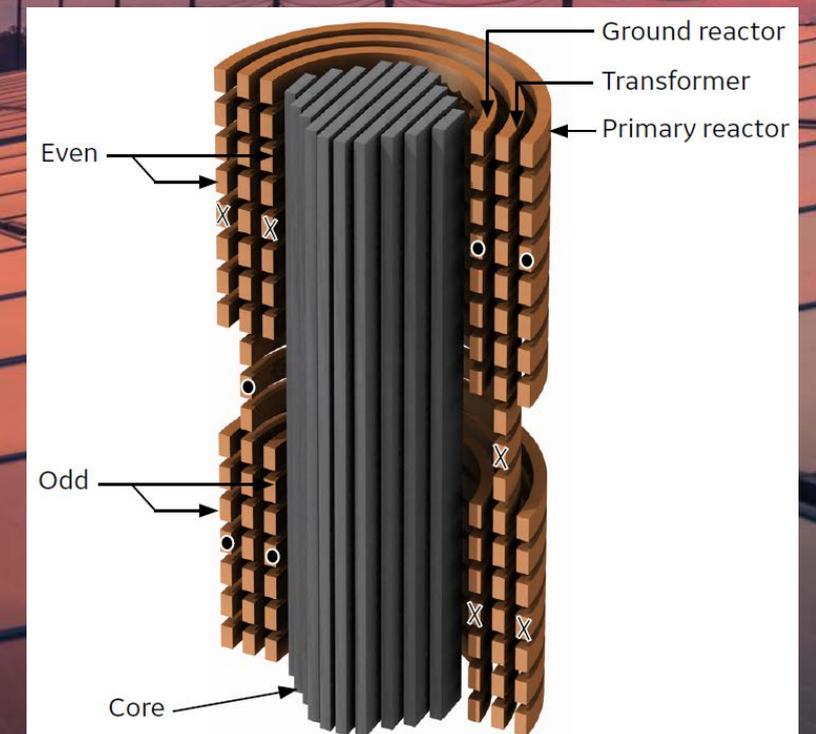
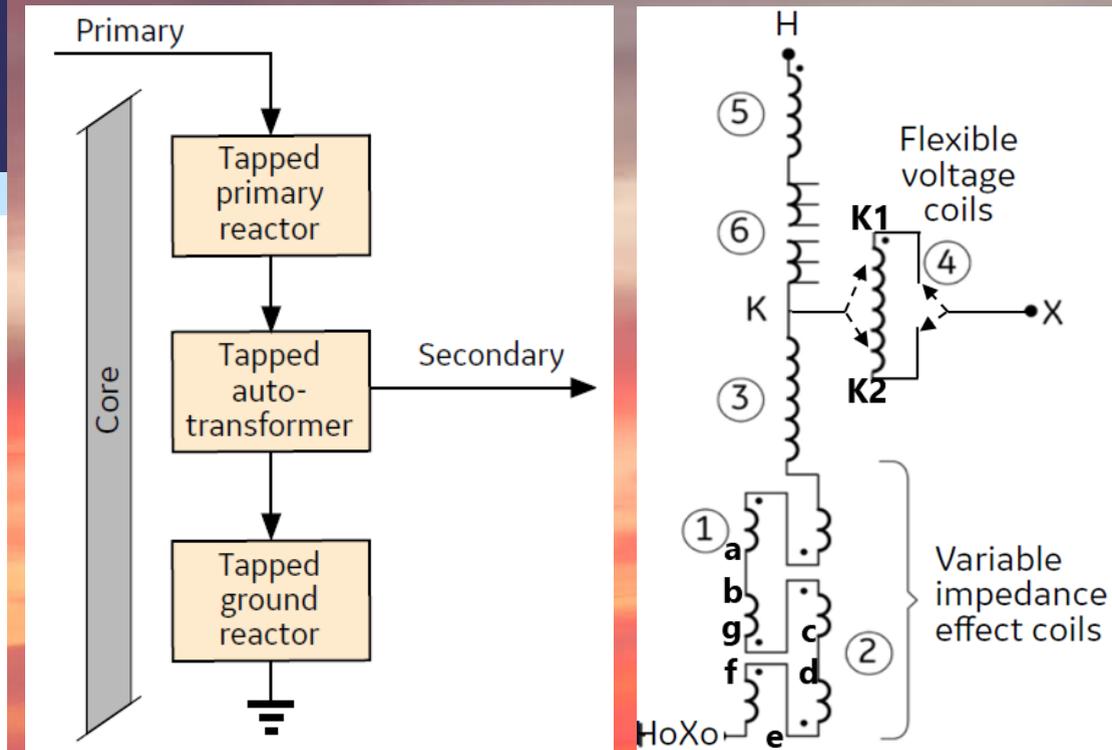
AWARDEE CONTRIBUTION (COST SHARE):

**\$593,981**

# Primary Innovation

A flexible autotransformer that has:

- 3 configurable transmission class voltage ratings at the secondary (e.g 161kV/138kV/115kV)
- a leakage impedance that is adjustable both online and offline in a wide range
- a leakage impedance selection independent from voltage configuration
- Used only existing and proven material



# Impact/Commercialization

- Can serve a universal spare to increase the grid resiliency, reduce LPT spare inventory, and reduce US dependency on foreign suppliers
- Increase the grid flexibility in power flow and voltage regulation and make its operation more adaptable to higher penetrations of renewable generation.
- Increase the grid reliability for severe events with control of short-circuit levels.
- NPI plans are in process at Prolec GE

## IP STATUS

- US 11,087,913 Transformer system – *issued*
- US 2021/0151235 A1 Flexible transformer system – published.
- A 3<sup>rd</sup> patent disclosure on protection is *pending*

# Innovation Update

- Completed the design and manufacturing of a 165kV, 60MVA prototype of a flexible LPT with configurable secondary at 57.5kV, 69kV and 80.5kV and a variable impedance from 4.3% to 9.3% (at 60MVA).
- Deployed and energized on 9/3/2021 with Cooperative Energy at Columbia, MS the prototype which became the world's 1<sup>st</sup> flexible LPT in operation.
- Deployed together with the prototype a flexible protection system that can automatically update protection settings online upon impedance change
- Prototype is undergoing 6 months of field validation with 4 months continuous operation already accrued.

# Prototype specifications

Autotransformer

60/80/100 MVA

(12/16/20 MVA External Tertiary)

		<u>Connection</u>	<u>BIL</u>
VH	161 kV	Y	650
VX	57.5/69/80.5 kV	auto	350/150
VY	13.8 kV	D	110
3Ph	ONAN/ONAF/ONAF	60 Hz	65 °C

On-line Impedance Variation range  
ZH-X = 4.2 to 9.3% @ 60 MVA

Voltage regulation (in LV line)

+/- 10% of rated voltage in 16 taps

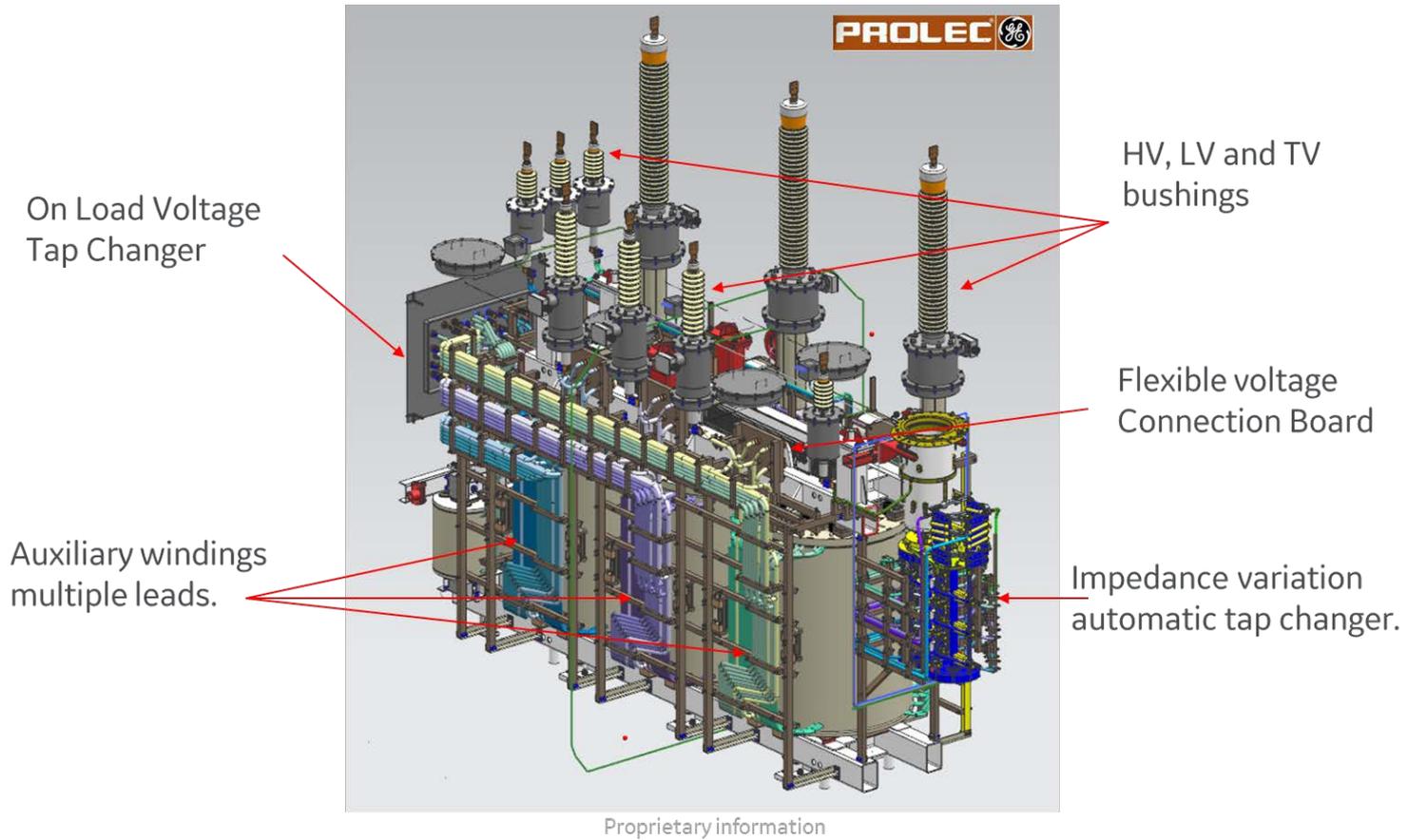
Designed and tested according to

- IEEE C57.12.00 IEEE Std for General Requirements of Liquid-Immersed Transformers
- IEEE C57.12.90 IEEE Std Test Code for General Requirements of Liquid-Immersed Transformers

Tested impedance values for 165kV/69kV configuration

IMPEDANCE @ 85°C									
IMPEDANCE TAP CHANGER DIAL POSITION	KV BASE								
	165.025 / 80.5 / 13.8			165.025 / 69 / 13.8			165.025 / 57.5 / 13.8		
	KVA BASE			KVA BASE			KVA BASE		
	69 000			60 000			54 000		
	%Z H-X	%Z H-Y	%Z X-Y	%Z H-X	%Z H-Y	%Z X-Y	%Z H-X	%Z H-Y	%Z X-Y
8R				9.34	4.495	3.060			
7R				8.714	4.611	3.125			
6R				8.125	4.734	3.216			
5R				7.568	4.861	3.324			
4R				7.045	4.992	3.45			
3R				6.549	5.124	3.597			
2R				6.090	5.254	3.762			
1R				5.666	5.395	3.943			
NOM				5.267	5.535	4.144			
1L				4.918	5.679	4.37			
2L				4.599	5.829	4.617			
3L				4.309	5.981	4.885			

# Design and commissioning of the prototype



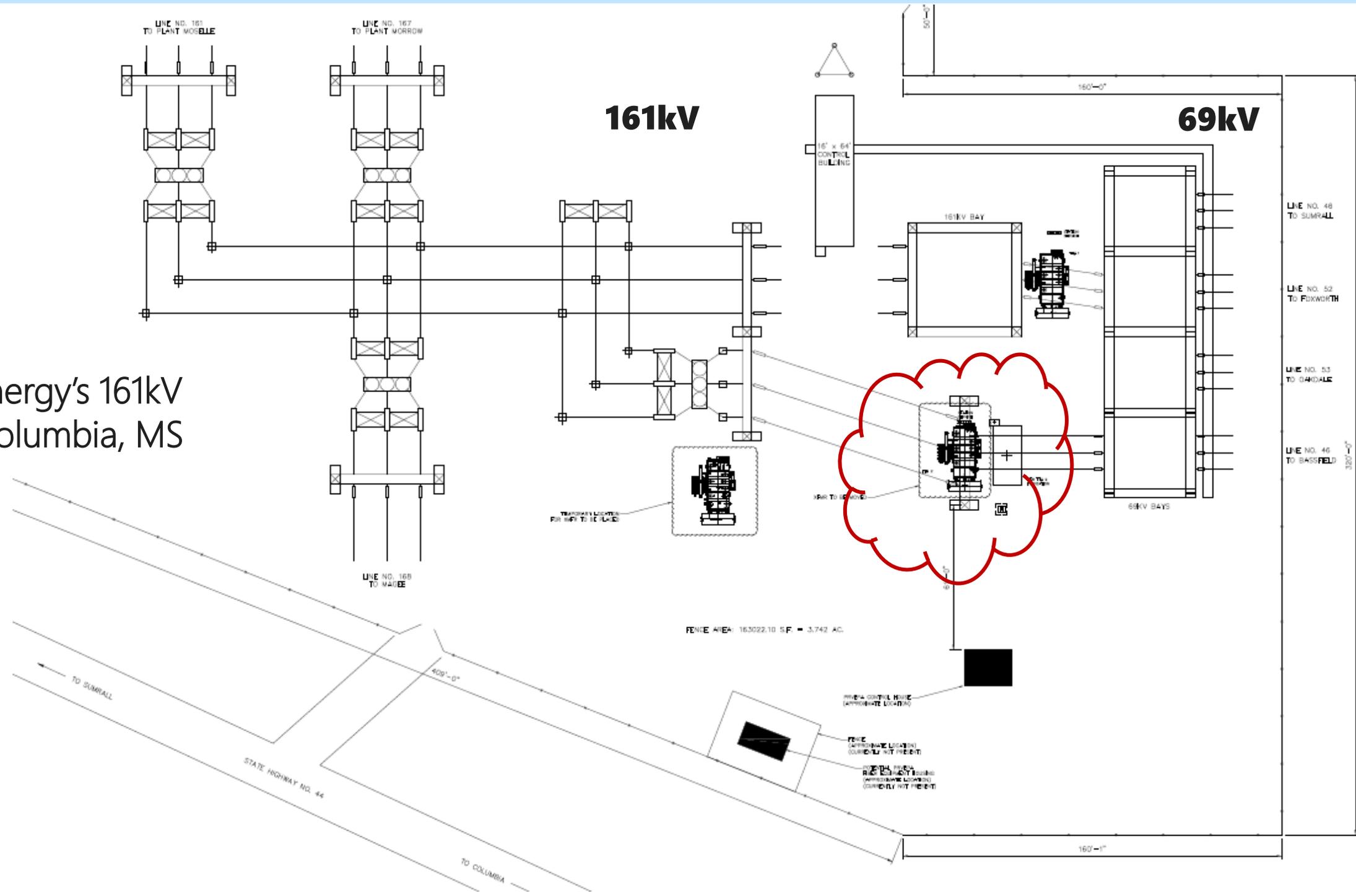
Internal layout of the designed flexible LPT prototype

Ztap position (MS3000)

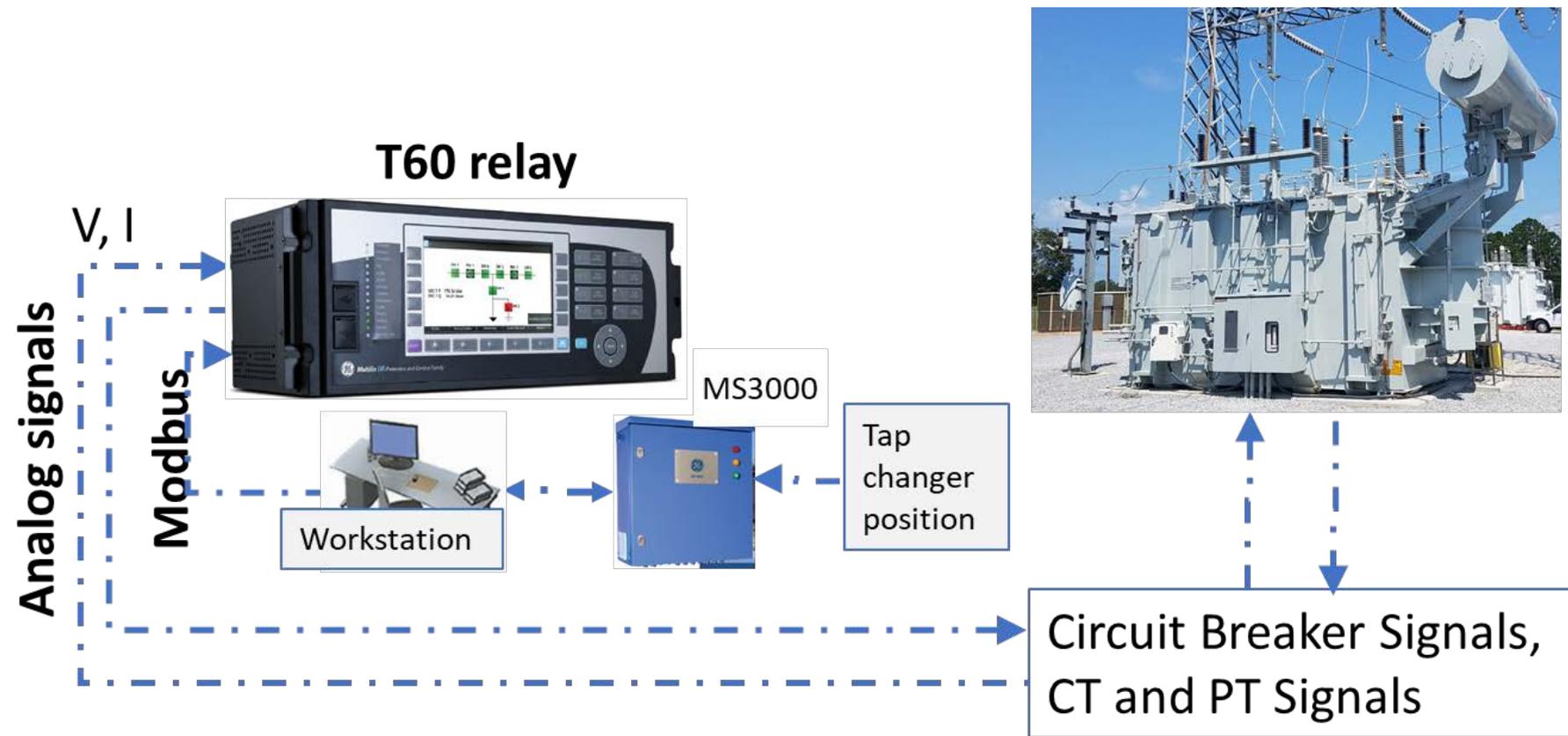


# Field validation site

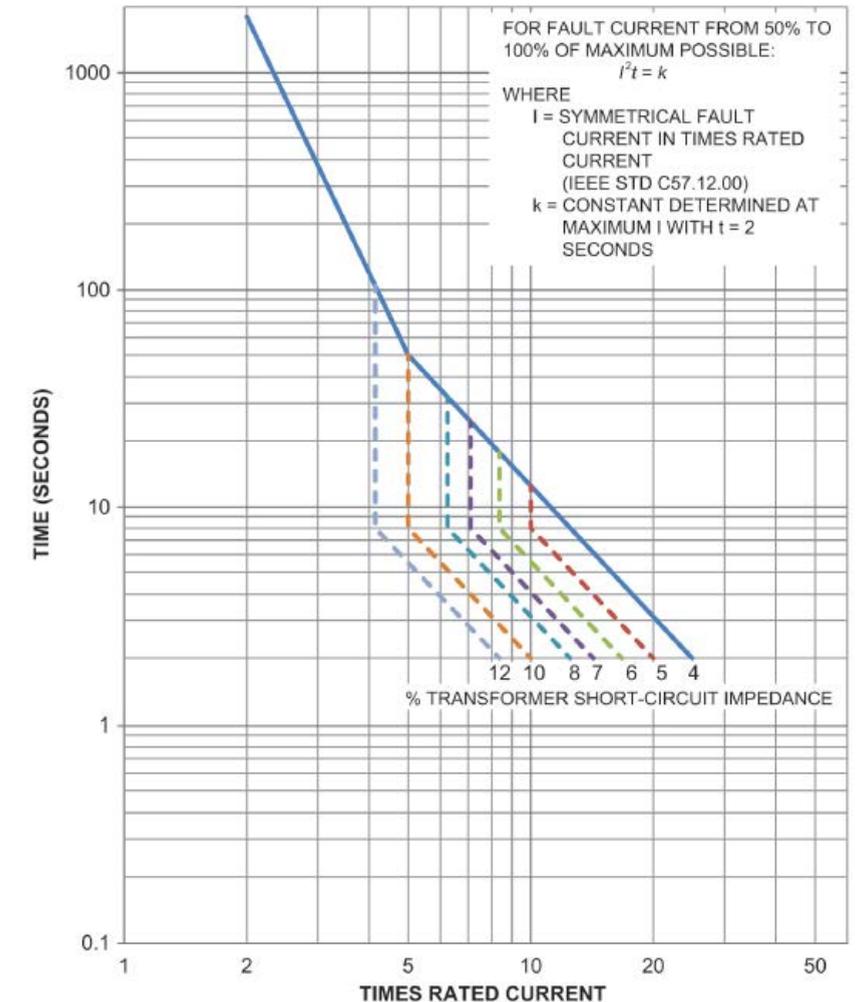
Cooperative Energy's 161kV substation in Columbia, MS



# Commissioning of the augmented protection relay

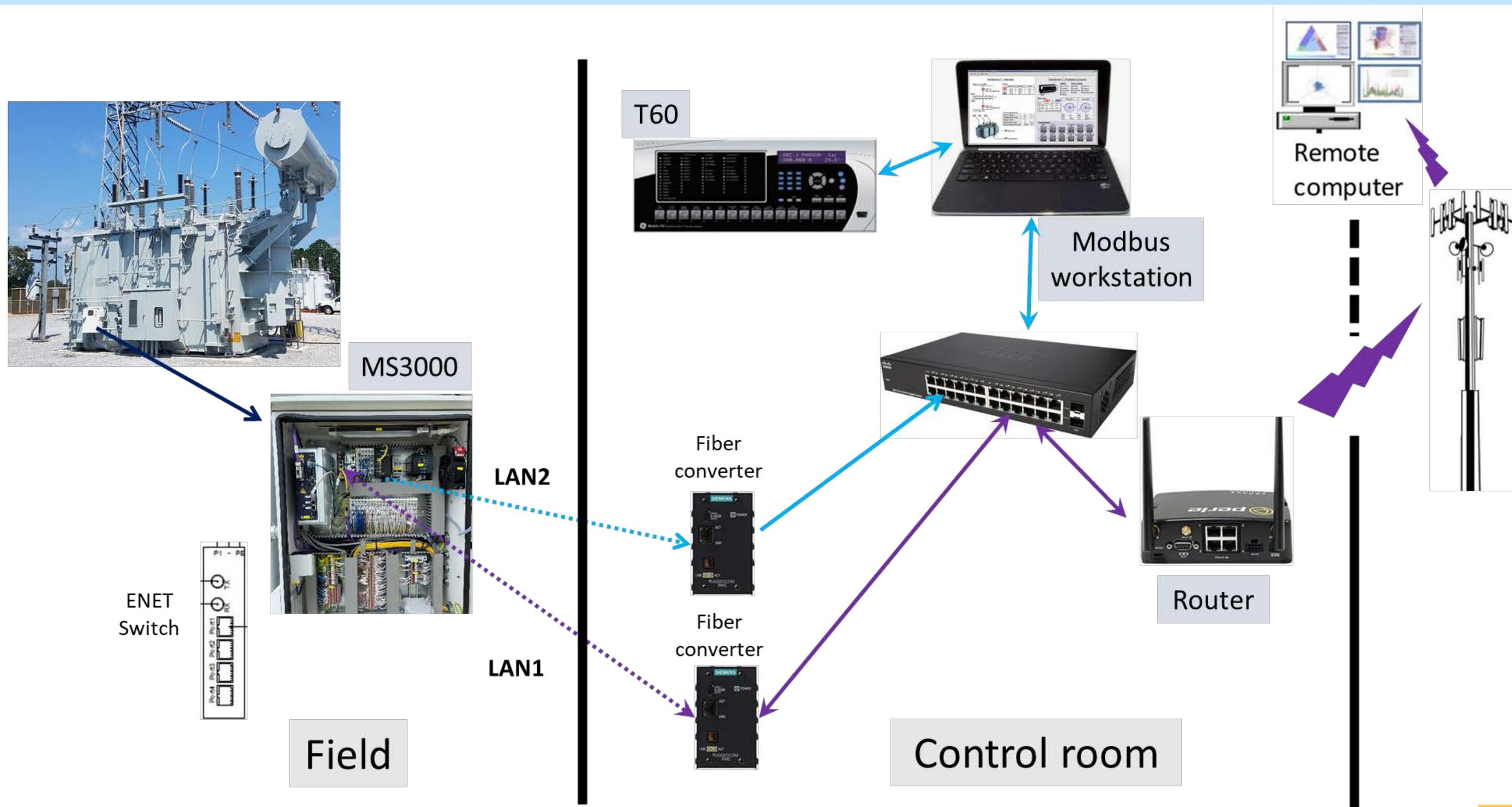


Development and commissioning of an augmented protection relay for the flexible LPT



IEEE Std C57.109-2018 IEEE Guide for Liquid Immersed Through Fault Current Duration

# Protection and monitoring system

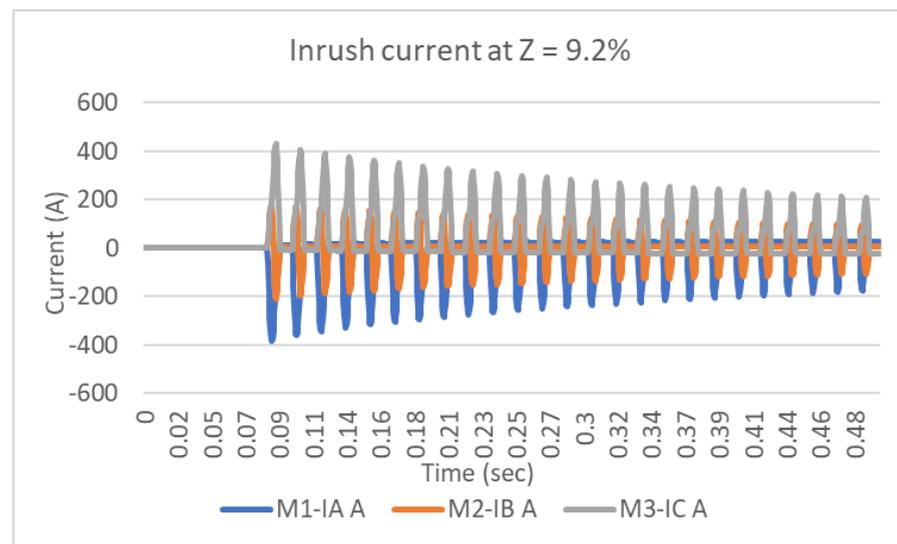
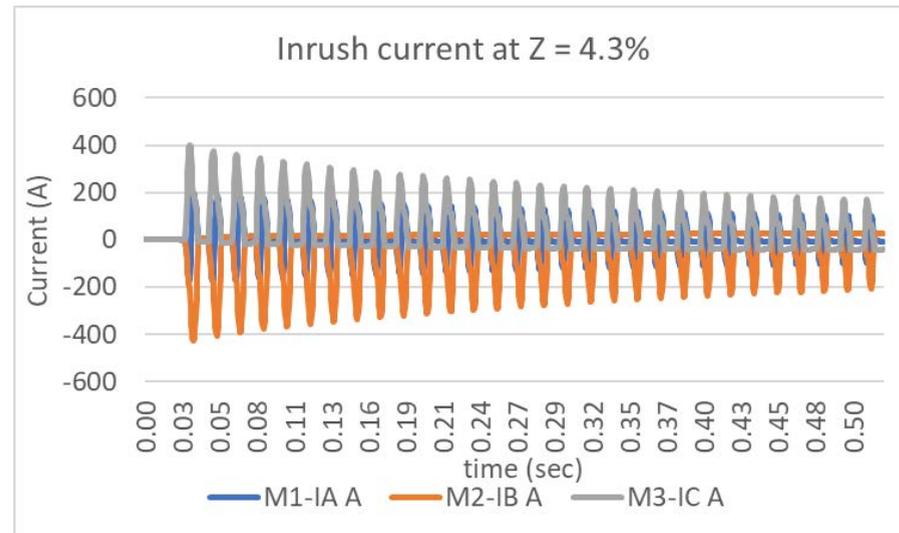


# World 1<sup>st</sup> Flexible LPT ready for operation

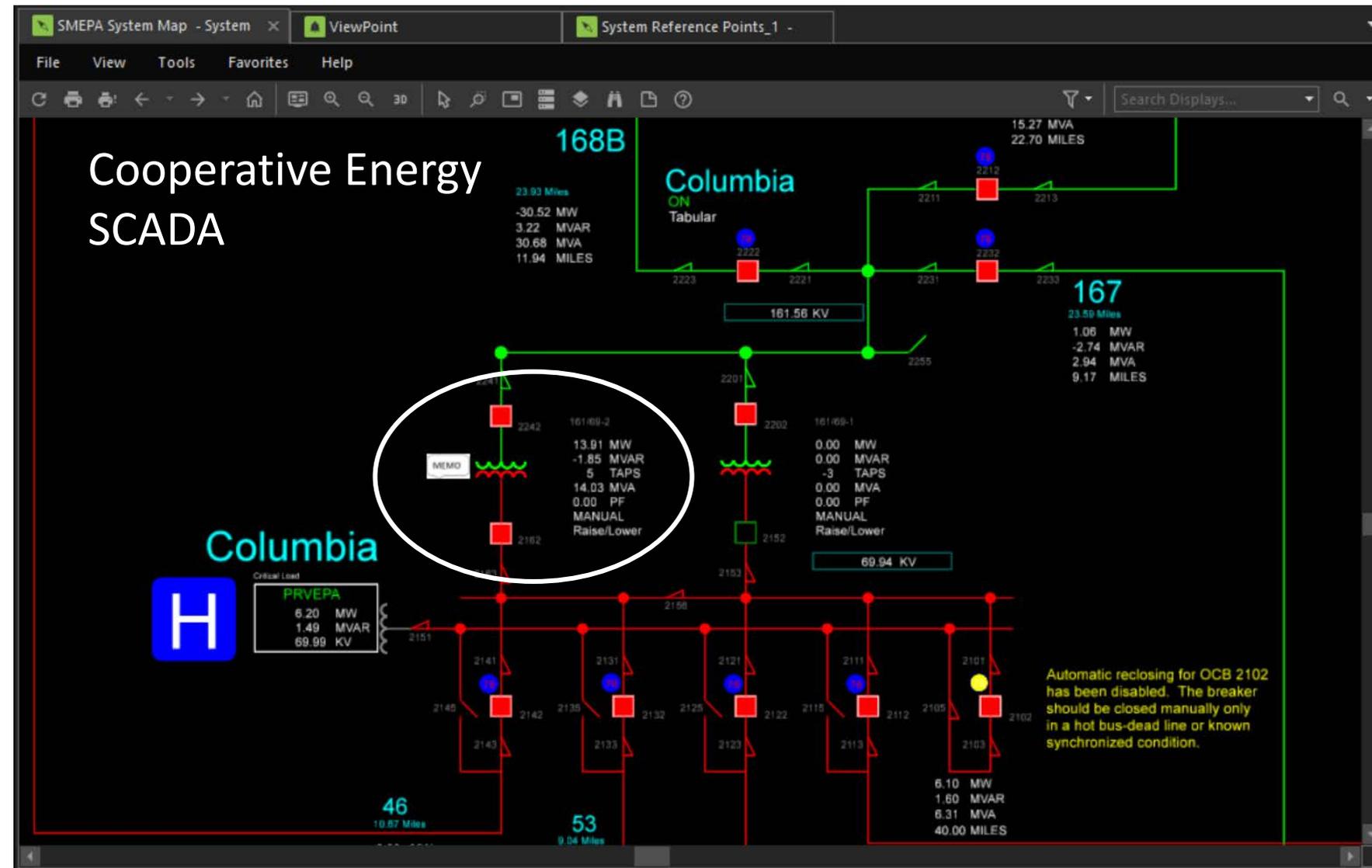


Prototype as installed at Cooperative Energy's 161kV substation in Columbia MS

# Energization of the prototype



Highest inrush current was 437A (1.22 of full load current); Significantly lower level as compared to conventional transformers.



14MVA throughput power after closing of LV breaker

# Remote monitoring system

The screenshot displays the MS 3000 Condition Monitoring and Expert System interface, powered by GE Renewable Energy. The system time is 01/09/22 20:47:04, and the user is logged in as 'ibrahima'. The interface is divided into several sections:

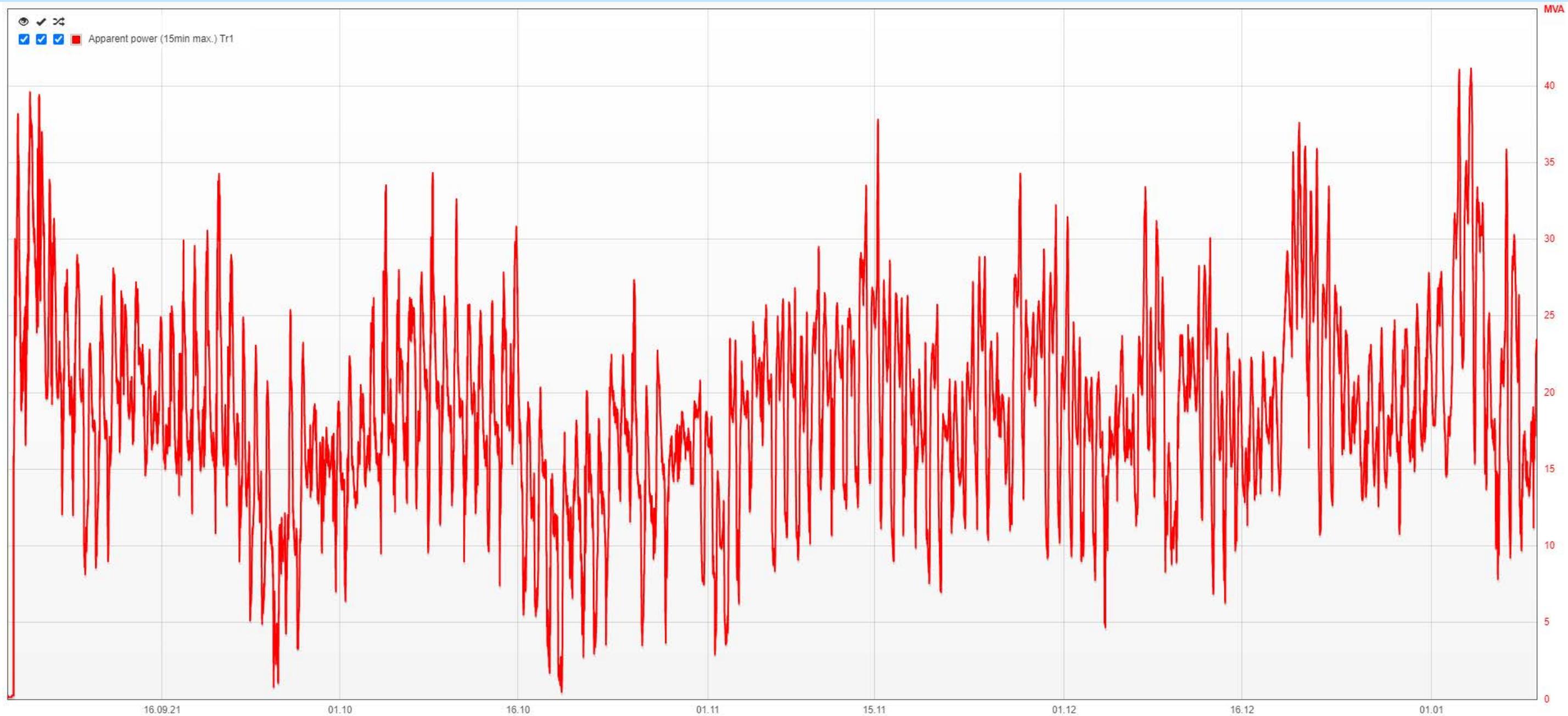
- System Information:** System time (01/09/22 20:47:04), System status (green bar), and User (ibrahima) with a logout option.
- ONLINE DATA:** A list of monitoring options including Status Overview, Alarms, TX1 (Active Part), Overload Calculation, Bushings HV, Bushings HV VT, Tap Changer, Cooling Unit, Conservator, Partial Discharges, Simulator, and Name Plate.
- HISTORICAL DATA:** Historical Data.
- TOOLS:** Tools.
- SYSTEM DATA:** System Data.

The main content area is titled 'Cooperative Energy' and includes a navigation menu: Loading + Current, Ageing + Lifetime, Online DGA, Insulation System, Temperatures, and Auxiliary Status. Two panels are open:

- Loading Panel:**
  - Status of transformer (ON/OFF): ON
  - Power (apparent power): 21 MVA
  - Power (active power): disabled MW
  - Power (reactive power): disabled MVar
  - Load factor: 0.21
  - Actual losses: 53 kW
  - Cos Phi: disabled
  - Transient Events:**
    - Number of overcurrents: 690
    - Last overcurrent: 01/02/22 04:32:59
- Currents Panel:**
  - Load current HV Ph. 1: 74 A
  - Load current HV Ph. 2: 79 A
  - Load current HV Ph. 3: 75 A
  - Load current MV Ph. 1: 172 A
  - Load current MV Ph. 2: 181 A
  - Load current MV Ph. 3: 174 A
  - Load current H0X0: 5 A
  - Load current TV: 0 A

Remote monitoring system reporting all the operating conditions and health status for the 6 months validation period and beyond

# Remote monitoring system



Prototype loading since energization (9/3/2021). Peak load of 41MVA has been observed

# The team!



The development and commissioning team, September 3<sup>rd</sup>, 2021, Columbia MS

# Acronyms

CT: Current transformer

GE: General Electric

HV: High voltage

IEEE: Institute of Electrical and Electronic Engineers

LV: Low voltage

LPT: Large power transformer

MVA: Mega volt ampere (transformer power rating unit)

NPI: New Product Introduction. A GE process for new products commercialization

PT: Potential transformer

SCADA: Supervisory control and data acquisition

Ztap: Position of the flexible impedance tap changer

**THANK YOU**